

## Bibliography

Method of hardening the surface of a workpiece using a beam, particularly a laser beam and device for executing this method

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30 The hardening of workpiece surfaces is carried out by the use of a beam (in particular, a laser beam) which is oscillated perpendicular to the feed direction. At the same time, the workpiece surface temperature is measured and its distribution in the feed direction is adjusted. Heat radiation from the laser spot (14) on the workpiece is transmitted by means of a partially transparent mirror (5) into a temperature check unit (17) for instantaneous determination of the surface temperature. The resulting temperature data is supplied to a control unit (28) governing the laser radiation energy, the beam deflection and the feed motion in such a way that a homogeneous surface temperature distribution is achieved along and across the feed direction. Also claimed is an apparatus for the above process.

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## Description

The invention concerns a procedure for hardening workpiece surfaces by means of light beams, in particular by means of laser beams, an optics for hardening with laser beam-forming capabilities and the workpiece surface are moved relatively to each other, the point of impact of the laser beam oscillates (reciprocates) during hardening because of a deflection movement of the optical unit (optics for hardening) transverse to the feed direction. The workpiece surface temperature is continuously measured and the distribution thereof along the feed direction is regulated.

10 The invention concerns a device for running the procedure, having an adjustable source of the light beam, in particular a solid state laser; having optics with a beam-forming deflecting system, from which the laser beam impinges on a workpiece surface and is reciprocated transverse to the feed direction; having a mechanism for producing a relative feed motion of the optics and the workpiece surface and having means for measuring the workpiece surface temperature.

15 Control and regulation of the workpiece surface temperature during beam hardening, e.g. hardening with the laser beam, is a necessary condition for the optimization of the working process. By keeping the distribution of the workpiece surface temperature so that the distribution is adapted, usually homogeneous and slightly below the fusing temperature, distributed along and transverse to the feed direction, given hardness track widths with even trace depths are reached with highest possible feed speed. At the same time such a control and regulation prevents damage of the surface by burning spots, which lowers costs of remachining and refuse.

20 It is well-known, during the treatment with precision of workpiece surfaces with solid state lasers, to use a pyrometer for obtaining the temperature of the workpiece surface (see e.g. "Precision treatment with solid state lasers" in "Lasers in the material processing", volume 4, 1995, publisher: VDI (= 25 association of German engineers) Technologiezentrum; physical technology). For collecting of the surface temperature of the workpiece usually pyrometric detectors are installed facing the workpiece and additionally to the laser beam-forming hardness optics and are moved together with the optics during the feed motion over the workpiece. The pyrometers determine the average temperature in the respective measuring spots. The hottest spot during the hardening procedure is, however, in each case the momentary point of impact of the laser beam, which reciprocates due to the beam forming deflecting system transverse to the feed direction, i.e. changes thus permanently and its temperature can be seized therefore only insufficiently in this way.

30 35 For obtaining workpiece surface temperatures as homogeneously as possible in a direction transverse to the feed direction, therefore are used up to now not energy distributions adapted to actual measurements, but constant beam

5 energy distributions are produced by means of given (adjusted) beam deflection forms. This known procedure leads, however, to satisfying results only in case of homogeneous workpieces and homogeneous workpiece surface properties as well as constant procedural conditions. In feed direction the average value of the beam energy distribution is controlled on the basis of the measured middle temperature in the pyrometer measuring spot.

A defined heating up of the workpiece surfaces is demanded even for different manufacturing processes. Therefore in processes of beam hardening workpiece surfaces the energy of the beam is formed in such a manner that it hits in a 10 certain form (geometrical shape and expansion and distribution) the workpiece surface. The beam is deflected and thereby moves over the workpiece surface. A goal of the invention is to observe the momentary point of impact of the beam on the workpiece surface and to measure the momentary temperature in the point of impact. An automatic controller coupled with the temperature 15 measurement generates certain correcting variables using different desired values and actual values, so that the demanded temperature distribution at the points of impact of the deflected beam is obtained, whereby by an actuator a relative motion between the workpiece surface and the tool (hardness optics) is produced, so that large surfaces can be beamed (illuminated). The automatic 20 control loops contained in the automatic controller thereby have to care for and ensure obtaining the demanded temperatures, which can be determined from work on-specific defaults, in each individual point of impact of the beam and the workpiece surface.

25 The invention is based on the task to make available a procedure and a device for its execution in accordance with the initially mentioned kind, which procedure and device allows to obtain a regulated distribution of the workpiece surface temperature along and transverse to the feed direction, so that steady (always remaining the same) hardening traces are produced with desired geometry, even in case of inhomogeneous workpiece surfaces.

30 This task is solved according to invention by the fact that

the heat radiation of the point of impact of the laser beam, which point of impact oscillates in the direction transverse to the feed direction, is supplied by means of partially transmitting (half-silvered) mirrors collinear to the path of rays of the work laser through the hardness optics towards a temperature controlling 35 device, by which always momentarily the temperature in the point of impact of the work laser beam spot is accurately seized, and that the determined temperature data are input into a controller, which controller is coupled with the source of the beam, with the beam deflection and with the feed motion, in which controller a temperature distribution is determined transverse to the feed 40 direction and by which controller a distribution of the laser beam energy co-ordinated with it and an adapted controlling of the deflection movement of the beam forming mechanisms of the hardness optics and the feed motion with consideration of work on-specific defaults is made in such a manner that a

homogeneous temperature distribution on the workpiece surface is produced along and transverse to the feed direction.

Preferably as work on-specific defaults are selected the material properties, the case hardening thickness, the warming up and cooling period, the workpiece geometry, the reciprocating movement, the feed motion and the operating time.

In feed direction the temperature of the hottest spot of the workpiece surface line illuminated by the laser is used for the regulation of the laser output level on the basis of the locally dissolved temperature measurement transverse to the feed direction.

10 A proportional regulation of the temperature can take place, therefore from the desired temperature signal the current temperature signal is subtracted and the difference obtained is multiplied by a factor X for the controlling of the laser beam output level, whereby the beam deflection is kept periodically sinusoidal and the feed speed is kept constant.

15 Also a complex regulation of the temperature can be accomplished, whereby from the temperature gradient obtained from a preceding working cycle a deflection movement is produced, which sets the demanded temperature for the following working cycle by fixing the appropriate speed, whereby for the adjustment of the active working time of the beam for each individual local point 20 in case of high temperatures the sweep rate is in sections increased and is lowered in sections with low temperatures, and whereby the beam deflection and the feed motion are held approximately in such a way that the source of the beam is always run at the power limit.

25 Known sections of missing workpiece surfaces (drillings or edges at the workpiece) are jumped over preferentially with high sweep rate.

If beam deflection and feed motion are in accordance with the ideal case in such a way that the source of beam is always held at its power limit, a relatively short operating time results. If during the beam deflection the demanded temperature is already reached with low beam output levels, feed speed can be increased up to the beam power limit.

The device according to invention for the execution of the procedure according to invention is characterized by the fact that

35 the hardness optics has an at least a partially transmitting mirror, by which directly the heat radiation from the point of impact of the work laser beam is supplied over the deflecting system and through the hardness optics towards a temperature controlling device, from which always momentarily the temperature at the point of impact of the work laser beam mark is taken also transverse to the feed direction, that the output of the temperature controlling device is

connected with an input of an automatic control loop, processing actual values, of an automatic controller, which receives the

measured data of the temperature distribution transverse to the feed direction for processing, and which is coupled to the exit of the source of beam, to the  
5 exit of the mechanism for producing the relative feed motion and to the of the drive of the deflecting system for receiving the actual values of the beam power, of the forward movement and of the beam deflection, that the automatic control loop processing actual values of the automatic controller has an exit which is coupled with the entrance of an automatic control loop of the automatic  
10 controller which automatic control loop produces correcting variables and is connected on its input side with the exit of a desired data processing automatic control loop of the automatic controller, whose entrance takes up work on-specific defaults, and that the exit of the automatic control loop producing  
15 correcting variables of the automatic controller is connected with the entrance of the source of beam, the entrance of the mechanism to produce the relative feed motion, and the entrance of the drive of the deflecting system, for the controlling of a distribution of the laser beam energy and/ or the feed motion and/ or beam deflection adapted to a homogeneous temperature gradient.

20 Preferably the temperature controlling device exhibits a deflecting mirror which is arranged in the flow of the heat radiation behind the partially transmitting mirror of the hardness optics, by which the heat radiation is guidable over a serial arrangement of a band pass filter, an aperture and a lens, from which lens the heat radiation is focused onto a subordinate aperture, which is followed by an IR detector in beam direction, which measures always accurately the  
25 temperature in the point of impact of the work laser beam reciprocating transverse to the feed direction.

The deflecting system of the hardness optics can be a scanning or a swiveling mirror.

30 Since in accordance with the invention it is ensured that the measured heat radiation of the workpiece surface travels through same optical way as does the laser beam including the entire laser beam forming deflection mirrors it is reached, that always accurately the temperature is measured of the point of impact of the laser beam. Due to the deflection movement of the beam forming mechanisms for the laser beam a distribution of the maximum workpiece  
35 surface temperatures transverse to the feed direction is obtained. By the following relatively fast measurement data processing it is possible to produce from the measured temperature distribution, and with suitable algorithms a distribution of the laser beam energy co-ordinated with it which ensures for the desired homogeneous temperature distribution. As correcting variables for this  
40 the possible geometric motions of the mobile beam deflection mirror used to the beam configuration is used, with a sufficiently fast controllable laser also the temporal behavior of the laser output can be used.

As special advantages of the invention prove:

Due to the locally dissolved temperature measurement and adapted control strategy the production of constant' hardening traces is obtained with desired geometry also for inhomogeneous workpiece surfaces;

- 5 the possible adherence to desired workpiece surface temperatures also in case of fluctuation of affecting procedural conditions, e.g. the intrinsic heat of the workpieces; the use of the same beam path for measuring radiation and for the laser radiation, whereby an accurate temperature measurement at the momentary point of impact (hottest spot) without large machine expenditure is
- 10 made possible;
- an unimpaired accessibility to the workpieces, there are no additional components facing the workpiece needed; and
- 15 the use of control members for temperature control (laser output control and programmable beam deflection systems) necessarily used for hardening anyway.

The invention is described now on the basis the drawing. The drawing shows in:

Fig. 1 a schematic representation in form of a block diagram of the device according to the invention for the execution of the procedure according to the invention,

- 20 Fig. 2 a diagram, which shows the measured temperature gradient during over the track width for a regulation by scanner influence of the beam energy distribution transverse to the processing direction,
- Fig. 3 a diagram, which shows for the example of Fig. 1 a compensated scanner course generated by the automatic controller,
- 25 Fig. 4 a diagram, in which the temperature is shown over the track length in working on direction and the regulation of the energy in feed direction,
- Fig. 5 a diagram, which shows the locally resolved temperature measurement during hardening and with temperature-controlled scanner movement,
- 30 Fig. 6 a diagram, which shows the locally resolved temperature measurement during hardening with a sinusoidal scanner movement and without use of the automatic controller,
- Fig. 7 a schematic representation, showing the gradual reaching of the planned trace depth without temperature control, and
- 35 Fig. 8 a schematic representation, showing that in case of temperature control the planned trace depth can be quickly reached.

As can be seen from Fig. 1, which shows a principle picture of the device for the regulation of the workpiece surface temperature, a light source 1, e.g. a solid state laser, produces a power beam 2 which is supplied to a laser beam-

40 forming hardness optics 4, in which the beam is directed by a lens 3 onto a partially transmitting deflecting mirror 5 and then directed after detour around 90 degrees by said deflecting mirror over a further lens 6 onto a swiveling mirror 8 controllable with regard to its sweep rate (arrow 7), from which the beam is focused for hardening purposes to a spot 13 on the surface 9 of a workpiece 12

moveable (see double arrow 11) by a driving motor 10, so that that the point of impact 14 of the spot 13 of the work laser beam during hardening reciprocates because of the deflection movement of the swiveling mirror 8 transverse to the feed direction 11 of the workpiece 12.

5 The heat radiation 15 emanating directly from the respective point of impact 14 of the laser spot 13 is passed collinear to the beam path 2 of the work laser 1 to the hardness optics 4, i.e. it runs, as shown in Fig. 1, from the point of impact 14 of the work laser beam spot 13 to the swiveling mirror 8 and from there over the lens 6 to the partially transmitting mirror 5 of the hardness optics 4, the  
 10 beam passes through the optics 4 and arrives at a deflecting mirror 16 of a temperature controlling device 17, from which the heat radiation after deflection of 90 degrees in the temperature controlling device 17 passes through an arrangement of a band pass filter 18, an aperture 19 and is focused by said lens 20 onto an aperture 21, which in beam direction is followed by an IR  
 15 detector 22. The lens 20 and the aperture 21 C8.11, as indicated by the double arrows 23 and 24, moved in beam direction and/or in a direction perpendicular to this beam direction. By the IR detector 22 the temperature in each point of impact 14 of the work laser beam is measured always accurately and directly.

20 With the IR detector 22 and thus with the exit 25 of the temperature controlling device 17 an entrance 26 of a actual values of processing automatic control loop 27 of an automatic controller 28 is connected, its exit 29 is connected with the entrance 30 of a control values producing automatic control loop 31 of the automatic controller 28. The entrance 30 of the automatic control loop 31 is further connected to an exit 32 of a further automatic control loop 33 of the  
 25 automatic controller 28 processing desired values, in whose entrance 34 work on-specific defaults are ready for input as working on parameters.

30 The entrance 26 of the automatic control loop 27 of the automatic controller 28 is further connected with the exit 35 of the source of beam 1, to the exit 36 of the feed motion of producing driving motor 10 and to the exit 37 of a drive 38 of the swiveling mirror 8 controllable with regard to its sweep rate for the receiving the actual beam power, the actual feed motion the actual beam deflection, respectively.

35 As work on-specific defaults, from which the demanded temperatures can be determined, e.g. material properties, the a hardening depth, the warming up and cooling period, the workpiece geometry, the moving movement, the feed motion and the operating time are entered to the entrance 34 of the processing automatic control loop 33 processing actual values of the automatic controller 28.

40 The exit 39 of the automatic control loop 31 of the automatic controller 28, in which from the actual values and desired values entered over the entrance 30 after their alignment thereof the necessary correcting variables are produced, is connected to the entrance 40 of the source of beam 1, to the entrance 41 of the

driving motor 10 and to the entrance 42 of the drive 38 of the swiveling mirror 8 for the controlling a distribution, adapted to the demanded homogeneous temperature gradient, of the laser beam energy, of the adapted feed motion and of the adapted beam deflection, respectively.

- 5 With a relatively fast measurement data processing of the momentarily accurately measured temperatures in the points of impact 14 of the work laser beam spot 13 an optimal homogeneous workpiece surface temperatures is always possible along and transverse to the feed direction 11 in a simple manner.
- 10 Fig. 2 and 3 stand in connection with a partial strategy for optimization of the method, with which the regulation of the beam energy distribution takes place transverse to the working on direction under scanner influence, whereby also a regulated surface temperature distribution of inhomogeneous workpiece characteristics e.g. local scaling, boreholes and the approximation at edges is aimed at. As Fig. 2 shows, from which the measured temperature distribution over the track width is apparent, the temperature is on the top right already nearly too hot, as the temperature approaches the fusing temperature Tschmelz.
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- 20 The diagram of Fig. 3 shows the compensated (regulated) scanner course generated by the automatic controller in this case, whereby a faster passage of the right trace side is to be recognized.

- 25 The diagram of Fig. 4, in which the temperature is shown over the trace length, is in connection with a further partial strategy for optimization of methods, with which a regulation of the energy takes place in feed direction (track energy or way energy). The temperature gradient shows that at point 1 a sinking of the laser power PL takes place and at point 2 an increase of the laser power PL is performed by the regulation of the linear energy in feed direction. Such a proceeding can be developed also in principle with commercial, locally less well dissolving measuring pyrometers, whereby, however, only a middle temperature of the zone treated is obtained and can be used as signal.
- 30 Because, however, according to invention the local resolution transverse to the feed direction is performed and measurements can be extremely fast, the procedure according to invention even with this partial strategy still proves more to be more precise, and e.g. the temperature of the actually hottest single locus can be used as signal.
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- 40 A third partial strategy for optimization of methods is based on regulated starting of the working movement, i.e. according to the invention with the temperature-controlled definition of the point of start. This proceeding, which can be made at any time of the regulation of the beam energy distribution transverse to the working on direction by scanner influence and the regulation of the energy in feed direction by coupling of the automatic controller with the driving motor for the feed motion, is likewise extremely precisely feasible.

From the diagram of Fig. 5 the locally dissolved temperature measurement comes out during hardening with temperature-controlled scanner movement, whereby the automatic controller adapts the scanner movement in such a way that as desired, as Fig. 5 shows, everywhere equal high temperatures develop.

5 The parameters are in this case as follows:  
 P = 2500 W  
 V = 0.7 m/min  
 beam diameter: 6.1 mm  
 width of scan: 14.6 mm

10 The diagram of Fig. 6, in contrast to this, shows the local temperature measurement during hardening with sinusoidal scanner movement without the employment of the automatic controller, whereby in edge near zones higher temperatures result and whereby within the middle zone lower temperatures result, as is apparent from the diagram.

15 The parameters are here the same as the ones given for Fig. 5.

The Fig. 7 and 8 show finally chart-like the gradual reaching of the planned trace depth when starting the feed motion during hardening without any temperature control and a fast reaching of the planned trace depth when starting the feed motion during hardening with temperature control in accordance with the partial strategy described above for optimization of methods.

#### List of the reference symbols

1 source of beam, solid state laser  
 2 power of beam, beam output, path of rays of the work laser  
 25 3 lens  
 4 hardness optics  
 5 partially transmitting deflecting mirror  
 6 lens  
 7 arrow for sweep rate  
 30 8 swiveling mirror  
 9 workpiece surface  
 10 driving motor  
 11 double arrow for feed directions  
 12 workpiece  
 35 13 work laser beam spot or mark  
 14 point of impact  
 15 heat radiation  
 16 deflecting mirror  
 17 temperature controlling device  
 40 18 band pass filters  
 19 aperture (hole)  
 20 lens

- 21 aperture (hole)
- 22 IR detector
- 23 double arrow for movement of the lens 20
- 24 double arrow for movement of the aperture 21
- 5 25 exit of the temperature controlling device
- 26 entrance of the automatic control loop 27
- 27 automatic control loop for processing actual values
- 28 automatic controller
- 29 exit of the automatic control loop 27 for actual values
- 10 30 entrance of the automatic control loop 31 for correcting variables
- 31 automatic control loop for correcting variables
- 32 exit of the automatic control loop 33 for desired values
- 33 automatic control loop for desired values
- 34 entrance of the automatic control loop 33 for desired values
- 15 35 exit of the source of beam 1
- 36 exit of the driving motor 10
- 37 exit of the drive 38 of the swiveling mirrors 8
- 38 drive of the swiveling mirror 8
- 39 exit of the automatic control loop 31 for correcting variables
- 20 40 entrance of the source of beam 1
- 41 entrance of the driving motor 10
- 42 entrance of the drive 38 of the swiveling mirror 8

## Claims

1. Procedure for hardening workpiece surfaces by means of light beams, in particular by means of laser beams, in which procedure an optics for hardening with laser beam-forming capabilities and the workpiece surface are moved relatively to each other, the point of impact of the laser beam oscillates (reciprocates) during hardening because of a deflection movement of the optics transverse to the feed direction, characterized by the fact that the heat radiation of the point of impact of the laser beam, which point of impact oscillates in the direction transverse to the feed direction, is supplied by means of partially transmitting (half-silvered) mirrors collinear to the path of rays of the work laser through the hardness optics towards a temperature controlling device, by which always momentarily the temperature in the point of impact of the work laser beam mark is accurately seized, and that the determined temperature data are input into a controller, which controller is coupled with the source of the beam, with the beam deflection and with the feed motion, in which controller a temperature distribution is determined transverse to the feed direction and by which controller a distribution of the laser beam energy co-ordinated with it and an adapted controlling of the deflection movement of the beam forming mechanisms of the hardness optics and the feed motion with consideration of work on-specific defaults is made in such a manner that a homogeneous temperature distribution on the workpiece surface is produced along and transverse to the feed direction.
2. Procedure according to claim 1, characterized by the fact that as work on specific defaults the material properties, the case hardening thickness, the warming up time and the cooling time, the workpiece geometry, the deflecting movement, the feed motion and the operating time are selected.
3. Procedure according to claim 1 and 2, characterized by the fact that a proportional regulation of the temperature takes place, as from the desired temperature signal the current temperature signal is subtracted and the difference obtained is multiplied by a factor X for the controlling of the beam power, whereby the beam deflection is kept periodically sinusoidal and the feed speed is kept constant.
4. Procedure according to claim 1 and 2, characterized by the fact that a complex regulation of the temperature takes place, whereby from the temperature gradient of a preceding duty cycle a deflection movement is produced, which sets the desired temperature for the following duty cycle by the appropriate speed, whereby for the adjustment of the active working period of the laser beam for each individual point in case of high temperatures the sweep rate is in sections increased and the sweep rate is lowered in sections where the temperature is too low, and whereby the beam deflection and the feed motion are held approximately in such a way that the source of beam is always operating at the power limit.

5. Procedure according to claim 4, characterized by the fact that known sections of the workpiece showing missing workpiece surface (drillings or edges at the workpiece) are jumped over with high a sweep rate.

6. Procedure according to claim 1 to 5, characterized by the fact that in feed direction the temperature of the hottest locus of the workpiece surface illuminated by the laser is used for the regulation of the laser power level using the locally effected temperature measurement transverse to the feed direction.

7. Device for the execution of the procedure according to claim 1 to 6, comprising an adjustable source of beam, in particular a solid state laser; a hardness optics having a beam-forming deflecting system, by which the work laser beam is directed on a workpiece surface in reciprocating movements transverse to the feed direction; a mechanism for producing a relative feed motion of the hardness optics and the workpiece surface; and means for seizing the workpiece surface temperature, characterized by the fact

15 - that the hardness optics (4) has an at least partially transmitting mirror (5), by which mirror directly the heat radiation (15) coming from the point of impact (14) of the work laser beam spot (13) is supplied over the deflecting system (8) and through the hardness optics (4) towards a temperature controlling device (17), which always momentarily measures the temperature at the point of impact (14)

20 of the work laser beam spot (13) also transverse to the feed direction (11);

- that the exit (25) of the temperature controlling device (17) is connected with an entrance (26) of an actual values processing automatic control loop (27) of an automatic controller (28), which receives the measuring data of the

25 temperature distribution transverse to the feed direction (11) for processing and which is connected with the exit (35) of the source of beam (1), the exit (36) of the mechanism (10) for producing the relative feed motion and the exit (37) the drive (38) of the deflecting system (8) for receiving the actual beam power and/ or the actual feed motion and/ or the actual beam deflection;

30 - that the actual values processing automatic control loop (27) of the automatic controller (28) has an exit, which is connected with the entrance (30) of a correcting variables producing automatic control loop (31) of the automatic controller (28), the entrance (34) thereof receiving work on-specific defaults (working on parameters); and

35 - that the exit (39) of the correcting variables producing automatic control loop (31) of the automatic controller (28) is connected with the entrance (40) of the source of beam (1), with the entrance (41) of the mechanism (10) for producing the relative feed motion (11) and with the entrance (41) of the drive (38) of the deflecting system (8) to control a homogeneous temperature gradient adapted distribution of the laser beam energy and/ or an adapted feed motion and/ or an adapted beam deflection.

40 8. Device according to claim 7, characterized in that the temperature controlling device (17) exhibits a deflecting mirror (16) arranged, in the direction of the light path of the heat radiation, behind the partially transmitting mirror (5) of the

hardness optics (4), from which the heat radiation (15) passes through a serial arrangement of a band pass filter (18), an aperture (19) and a lens (20), from which lens the heat radiation (15) is focusable on a subordinate aperture (21), which is followed in beam direction by an IR detector (22), which measures the temperature in the point of impact (14) of the work laser beam spot (13) reciprocating transverse to the feed direction (11) accurately.

9. Device according to claim 7 and 8, characterized in that the deflecting system (8) of the hardness optics (4) is a swiveling mirror.

10. Device according to claim 7 and 8, characterized in that the deflecting system (8) of the hardness optics (4) is a scanner mirror.